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ORIGINAL PAPER

Evidence gaps and biodiversity threats facing the marine environment of the United Kingdom's Overseas Territories

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Abstract
Understanding the evidence base and identifying threats to the marine environment is critical to ensure cost-effective management and to identify priorities for future research. The United Kingdom (UK) government is responsible for approximately 2% of the world's oceans, most of which belongs to its 14 Overseas Territories (UKOTs). Containing biodiversity of global significance, and far in excess of the UK mainland's domestic species, there has recently been a strong desire from many of the UKOTs, the UK Government, and NGOs to improve marine management in these places. Implementing evidence-based marine policy is, however, challenged by the disparate nature of scientific research in the UKOTs and knowledge gaps about the threats they face. Here, we address these issues by systematically searching for scientific literature which has examined UKOT marine biodiversity and by exploring publicly available spatial threat data. We find that UKOT marine biodiversity has received consistent, but largely low, levels of scientific interest, and there is considerable geographical and subject bias in research effort. Of particular concern is the lack of research focus on management or threats to biodiversity. The extent and intensity of threats vary amongst and within the UKOTs but unsurprisingly, climate change associated threats affect them all and direct human stressors are more prevalent in those with higher human populations. To meet global goals for effective conservation and management, there is an urgent need for additional and continued investment in research and management in the Overseas Territories, particularly those that have been of lesser focus.

Keywords Anthropogenic threats · Marine biodiversity conservation · Evidence base · Gap analysis · Research synthesis · UKOTs

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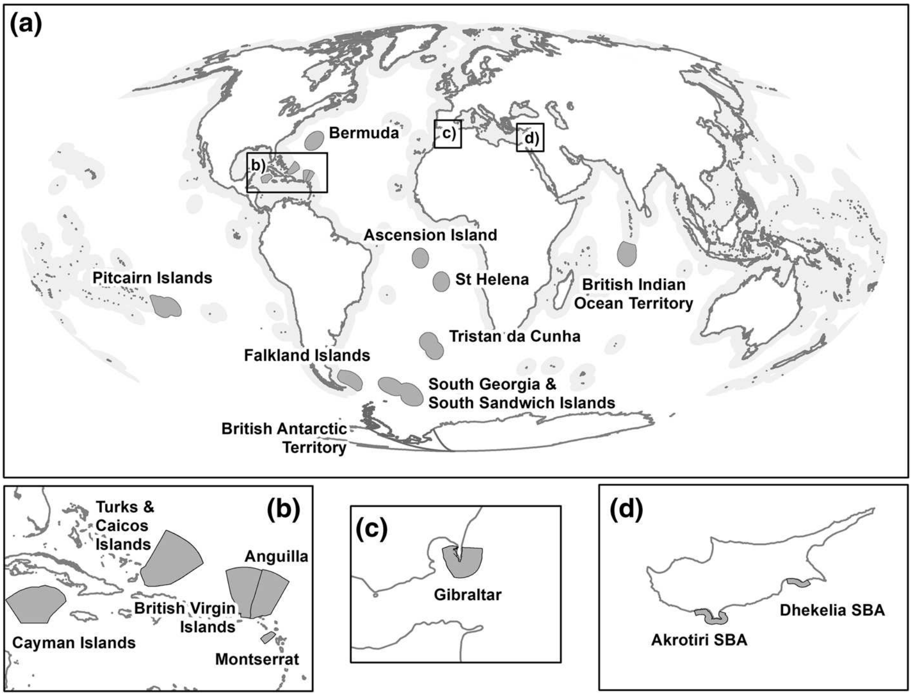


Fig. 1 Marine areas of the United Kingdom's Overseas Territories (UKOTS). World exclusive economic zones are shown in grey scale in map (**a**). Note that several of the UKOTs are subject to disputes by other countries and that the British Antarctic Territory legally has no marine waters in accordance with the Antarctic Treaty. Sovereign Base Area is abbreviated to SBA in (**d**)

Introduction

Scientific evidence is an essential component of the evidence toolkit for informing future research direction and management decisions (Dicks et al. 2014). Incomplete data and limited knowledge, together with inadequate staff and budget capacity, present challenges for ensuring effective conservation and environmental management (Gill et al. 2017; Kingsford et al. 2009). The United Kingdom (UK) government is responsible for approximately 2% of the world's ocean (approx. 6.8 million km^2). Just 11% (approx. 770,000 km^2) of this lies within the UK's domestic exclusive economic zone (EEZ) with the remainder spread across its 14 Overseas Territories (UKOTs) and their associated waters (Fig. 1). The vast area of marine waters that fall under the jurisdiction of the UKOTs contain a wealth of biodiversity (Churchyard et al. 2016; Dawson et al. 2014; Friedlander et al. 2014; Sheppard et al. 2012; Weber et al. 2014) much of which underpins ecosystem goods and services, predominately fisheries and tourism, upon which local communities, where present, often depend for their livelihoods (e.g. Amoamo 2013; Baker et al. 2015; Forster et al. 2014; Lester et al. 2017). However, a recent stock-take of marine biodiversity out to 12 nautical miles (nm) in the UKOTs concluded that knowledge of their marine species is poor and of variable quality (Churchyard et al. 2016).

The UKOTs largely comprise islands and archipelagos spread across the Atlantic, Indian, Pacific and Southern Oceans, and the Caribbean Sea (Fig. 1). The three exceptions are Gibraltar, which is part of the European mainland, and Akrotiri and Dhekelia Sovereign Base Areas and the British Antarctic Territory (BAT) which are part of larger landmasses. All UKOTs have permanent civilian populations apart from BAT, South Georgia and the South Sandwich Islands (SGSSI), and the British Indian Ocean Territory (BIOT). The United Nations has recognised Henderson Island (part of the Pitcairn Islands group) and Gough and Inaccessible Islands (which fall under the jurisdiction of Tristan da Cunha) as World Heritage sites for biodiversity due to their largely intact ecology because of minimal human disturbance and the presence of endemic species, particularly seabirds (UNESCO 1988, 1995).

The UK has committed to the Convention on Biological Diversity's target of protecting at least 10% of the marine environment by 2020 (Convention on Biological Diversity 2010; also adopted within Sustainable Development Goal 14.5, United Nations 2015). Contributing to this goal, the UK Conservative Party made a manifesto commitment in 2015 to create a 'Blue Belt of marine protection' around the UK and its Overseas Territories (The Conservative Party 2015), and this has now been adopted by the UK's other major political party (The Conservative Party 2017; The Labour Party 2017). Four large-scale marine protected areas (MPAs, $\geq$ 100,000 km^2) have already been designated, with plans for two more announced (Table 1). Two of these, the Chagos Archipelago MPA and the Pitcairn Islands Marine Reserve, have been established as full no-take areas, closed to all fishing (Government of Pitcairn Islands 2016; Sheppard et al. 2012). Recognising the importance of resource capacity for effective MPA management (Gill et al. 2017), the UK government committed funds of approximately £20 million over 4 years at the 2016 Our Ocean conference (Washington DC) to implement and monitor large-scale MPAs around the UKOTs, focusing initially on BIOT, SGSSI, BAT, the Pitcairn Islands, Ascension Island, St Helena, and Tristan da Cunha (UK Government 2017).

Ensuring effective marine management within the UKOTs and the ability to monitor the effectiveness of management actions, such as marine protected areas (MPAs), requires good knowledge of biodiversity and threats facing marine life. However, scientific research conducted within the various UKOTs is presented through a disparate literature and a comprehensive assessment of this and the extent of threats facing UKOTs is currently lacking. Here, we address these issues by systematically searching for scientific literature which has examined marine biodiversity in the UKOTs and by exploring publicly available spatial threat data (Halpern et al. 2015, 2008). The objectives of this study are three-fold: (1) to comprehensively collate and describe marine biodiversity research within the UKOTs to assist decision-makers and researchers in targeting gaps in the evidence base; (2) to broadly identify the main threats affecting marine biodiversity in the UKOTs; and (3) to evaluate the extent to which scientific research is addressing threats facing marine biodiversity within the UKOTs.

Methods

The UKOTs consist of: Anguilla, the British Virgin Islands (BVI), the Cayman Islands, Montserrat, and the Turks and Caicos Islands (TCI) in the Caribbean; Bermuda in the North-western Atlantic; Ascension, St Helena, and Tristan da Cunha, and the Falkland Islands in the South Atlantic; the British Antarctic Territory (BAT) and South Georgia and the South Sandwich Islands (SGSSI) in the Southern Ocean; the British Indian Ocean Territory (BIOT, also known as Chagos) in the Indian Ocean; Pitcairn, Henderson, Ducie and

Table 1 Large-scale marine protected areas (LSMPA, > 100,000 km^2) in the UK Overseas Territories as of January 2018

LSMPA name	UKOT	Approx. surface area (km^2)	No-take percentage of LSMPA	Details
Tristan da Cunha regime for marine protection	Ascension, St Helena, and Tristan da Cunha	750,000	Unknown	Designation with a management plan intended by 2020
St Helena Marine Protected Area		444,916	0	Designated 2016
Ascension Island Ocean Sanctuary		234,291	100	Designation with a management plan intended by 2019
Pitcairn Islands Marine Reserve	Pitcairn, Henderson, Ducie and Oeno Islands	834,334	100	Designated 2016
South Georgia and South Sandwich Islands Marine Protected Area	South Georgia and South Sandwich Islands	1,070,000	2	Designated 2012
Chagos Archipelago Marine Protected Area	British Indian Ocean Territory	639,661	100	Designated 2010 with interim management plan

Oeno Islands (also known as the Pitcairn Islands) in the South Pacific; and Gibraltar and the Sovereign Base Areas (SBAs) of Akrotiri and Dhekelia in the Mediterranean. Note that while there are only 14 qualifying territories, these have been separated into 16 analysis areas for the purposes of this study by treating Ascension, St Helena and Tristan da Cunha separately (Fig. 1). Note also that several of the UKOTs are subject to disputes by other countries [Akrotiri and Dhekelia SBAs by Cyprus, BAT by Chile and Argentina, BIOT by Mauritius and Seychelles, Falkland Islands by Argentina, and Gibraltar with Spain, and SGSSI by Argentina (Huth and Allee 2003)] and that BAT legally has no marine waters in accordance with The Antarctic Treaty (1959). We have consequently not undertaken a threat analysis for the waters around BAT, however to provide a comprehensive assessment and ensure future relevance of our research directory we have included waters surrounding BAT within the literature review.

Literature review

An intensive search of peer-reviewed scientific literature was undertaken in Web of Science and Scopus using the search string: [(Anguilla OR Bermuda OR "British Antarctic Territory" OR BAT OR "British Indian Ocean Territory" OR Chagos OR BIOT OR "Virgin Islands" OR BVI OR (Cayman AND island*) OR "Falkland Islands" OR Gibraltar OR Montserrat OR "Pitcairn Island*" OR "Henderson Island" OR Ducie OR Oeno OR "Saint Helena" OR Ascension OR "Tristan da Cunha" OR "South Georgia" OR "South Sandwich Islands" OR Akrotiri OR Dhekelia OR "Turks and Caicos Islands" OR TCI OR (Turks AND island*) OR (Caicos AND island*) OR [(UK OR "United Kingdom" OR British) AND ("overseas territor*")] AND (marine OR ocean OR coast*)].

Searches were initially run to capture all potentially relevant articles however only studies published in English and post-2006 were screened to restrict our assessment to the most recent decade of publication and to ensure a manageable return of literature. This represents approximately 50% of all scientific literature returned. Searches were undertaken between February and August 2017. The results from each search were combined in a single Endnote library file and duplicates removed. Grey literature, research not published in traditional academic journals, were not included within this assessment due to the difficulty in locating it and the time constraints of the study, however see Carine et al. (2015) for an assessment of biodiversity focused literature between 2009 and 2015 for both terrestrial and marine environments.

Retrieved articles were assessed for inclusion in our review according to a hierarchical assessment of relevance by screening article titles and abstracts, then full text of potentially relevant articles (Fig. 2). The aim of this process was to systematically remove articles that did not contain relevant information for our study. Studies were considered relevant if they were undertaken within UKOT marine waters, were of primary research (e.g. field, laboratory, modelling-based) and relevance to present day marine biology, biodiversity, ecology, and/or had a direct marine conservation/management outcome. Relevant reviews of UKOT waters were recorded separately. Note, only articles from, or that report direct use of, UKOT waters are reported. Studies conducted in nearby regions are also likely to be relevant for inference but were not searched for or included when identified.

Summary data (UKOT covered, full article reference, publication year, broad research focus, biological group studied) from each relevant article were extracted into a Microsoft Excel spreadsheet for descriptive analysis.

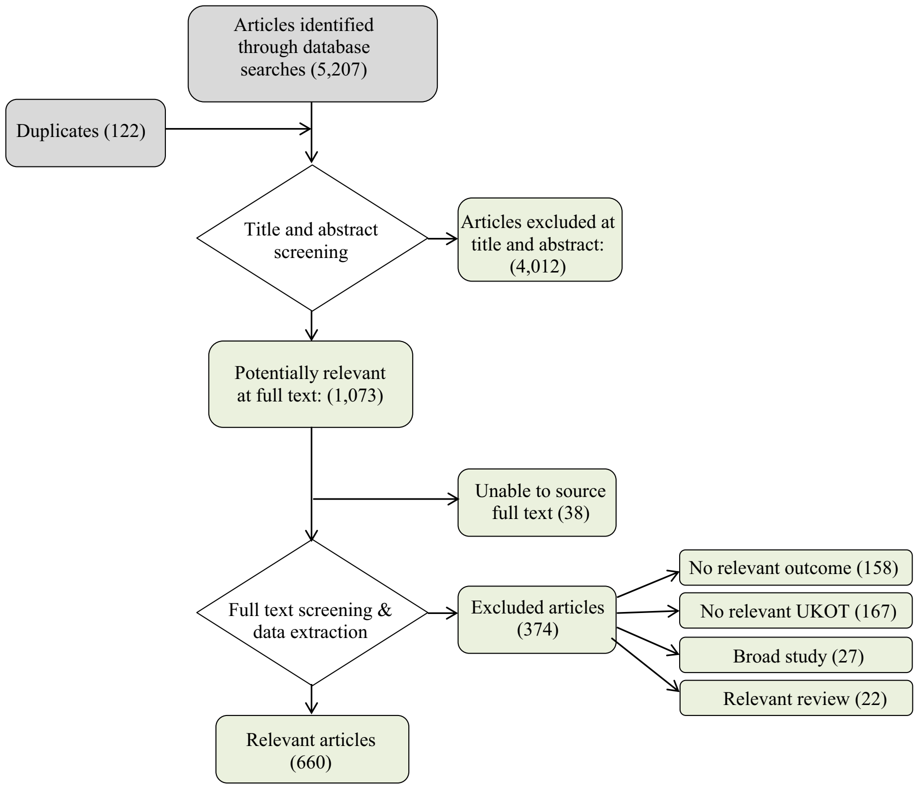


Fig. 2 Schematic of review stages from searches. Grey boxes represent inputs; diamonds: processes; arrows: information flow; and pale green boxes: outputs. Numbers in brackets represent the number of articles involved at each stage

Spatial analysis of biodiversity threats

UK Overseas Territory marine limits were downloaded from the UK government's Hydrographic Office.[1] Raw raster data for 19 global anthropogenic stressors to the ocean were used from Halpern et al. (2015) (Table 2). Note that other threats, such as disease (van Woesik and Randall 2017), noise (Haver et al. 2017) and crown-of-thorns outbreaks (Roche et al. 2015), face the UKOT's marine environment but were not considered in the spatial analysis of threats due to a lack of comprehensive spatial data beyond these studies focussed on specific locations. Raw stressor data were clipped to the extent of the UKOTs to remove high intensity values in busier seascapes and scale threats relative to the UKOTs. Stressor data were then transformed using a $\log(x+1)$ to ensure a normal distribution for all layers and rescaled on a continuous scale between 0 and 1 replicating processing methods from Halpern et al. (2008). To enable standardised comparison between stressors, each layer was rescaled using Eq. 1 for pixel i in layer j. This placed each pixel onto a unitless

[1] UK Hydrographic Office (last updated 2015). UK, UK Overseas Territories and UK Crown Dependencies Maritime Limits and Law of the Sea. [online] www.gov.uk/guidance/uk-maritime-limits-and-law-of-the-sea.

Table 2 Anthropogenic threat data analysed. Data obtained from Halpern et al. (2015) and Halpern et al. (2008) where detailed information on data sources and processing methods can be found

Threat category	Component stressors	Threat description
Climate change associated	Ocean acidification	Difference in Aragonite Saturation State between 1870 and 2000–2009
	Sea level rise	Satellite-derived sea level rise
	Sea surface temperature anomalies	Difference in temperature anomaly frequency between 2000–2005 and 1985–1990
	UV radiation	Frequency that erythemal UV light anomalies exceeded mean value + 1 standard deviation
Fishing	Artisanal	Modelled based on coastline length, unemployment rate, and total reported catch
	Demersal, non-destructive, high bycatch	Fishing practices targeting demersal species which do not modify habitats and have high bycatch rates
	Demersal, non-destructive, low bycatch	Fishing practices targeting demersal species which do not modify habitats and have low bycatch rates
	Pelagic, high bycatch	Fishing practices targeting pelagic species which have high bycatch rates
	Pelagic, low bycatch	Fishing practices targeting pelagic species which have low bycatch rates
	Demersal destructive, high bycatch*	Habitat-modifying fishing practices targeting demersal species high bycatch
	Demersal destructive, low bycatch*	Habitat-modifying fishing practices targeting demersal species low bycatch
Other human	Inorganic pollution	Urban pollution as runoff based on coastal population densities
	Ocean pollution	Based on activity of both commercial and recreational ships
	Invasive species	Modelled potential threat based on volume of cargo traffic in ports
	Direct human impact	Determined as population within 25 km of the coast
	Night lights	Presence/absence of moving light at night over the ocean.
	Fertiliser plumes	Nutrient input based on annual use between 1993 and 2002
	Pesticide plumes	Organic pollution based on annual average pesticide use between 1992 and 2001
	Shipping	Number of merchant ships above 1000 gross tonnes voluntarily being tracked at sea over 12 months from Oct 2004

The latter source is indicated by an asterisk

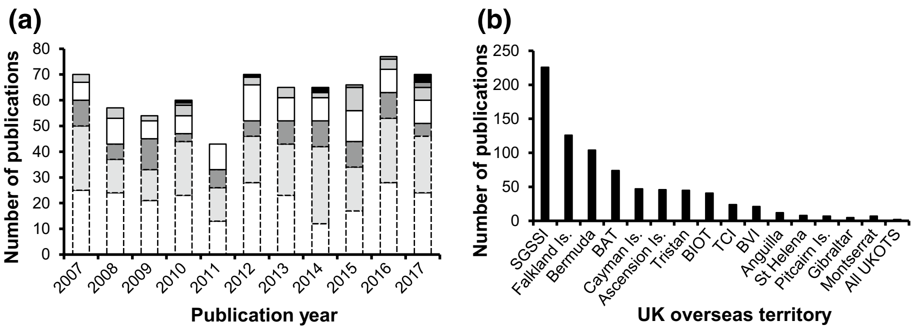


Fig. 3 Distribution of articles included in the review by **a** publication year, and **b** UK Overseas Territory studied. **a** Articles are categorised by region: white dashed outline Southern Ocean, pale grey dashed outline South Atlantic, dark grey dashed outline Caribbean, white solid outline North-western Atlantic, pale grey solid outline Indian Ocean, dark grey solid outline Mediterranean Sea, black Pacific. **b** Abbreviations: *SGSSI* South Georgia and South Sandwich Islands, *Is.* island(s), *BAT* British Antarctic Territory, *BIOT* British Indian Ocean Territory, *Tristan* Tristan da Cunha, *TCI* Turks & Caicos Islands, *BVI* British Virgin Islands. Akrotiri & Dhekelia Sovereign Base Areas are not included in **b** as no articles were identified in this UKOT

scale between 1 and 0, where 1 is highest intensity and 0 is lowest intensity, thereby allowing stressors to be ranked and compared against each other.

$$x = \frac{x_i - min_j}{max_j - min_j} \tag{1}$$

Individual stressors were then combined using a simple additive model to provide an overall threat score of 0–N for N layers. Note that for the purpose of this study, we assume that stressors are equivalent to threats, however threat level will vary across different activities and within the same activity type, and will affect species and habitats differently. Our results therefore represent an indication of the potential total intensity of threat contributed by all studied stressors facing each UKOT, based on data from Halpern et al. (2015) and Halpern et al. (2008). Although it is acknowledged that all 19 stressors are linked to anthropogenic drivers, similar stressors were divided into three categories for analysis: 'climate change associated' (e.g. sea surface temperature anomalies), 'fishing', and 'other human' (e.g. pollution) stressors (Table 2).

To examine the relative risk to each UKOT, the mean value for each stressor category was extracted and threat levels mapped to explore spatial variability. All data were analysed for each 1 km^2 cell of ocean and projected to WGS-1984 Mollweide. Data processing and statistical analysis were conducted in R v.3.4.1 and Microsoft Excel. Spatial analysis was undertaken using ArcGIS 10.4.

Results

Evidence map generated from the literature review

We identified 660 relevant articles published between 2007 and August 2017 (Fig. 3a, Table S1). On average 60 articles studying at least one UKOT were published each

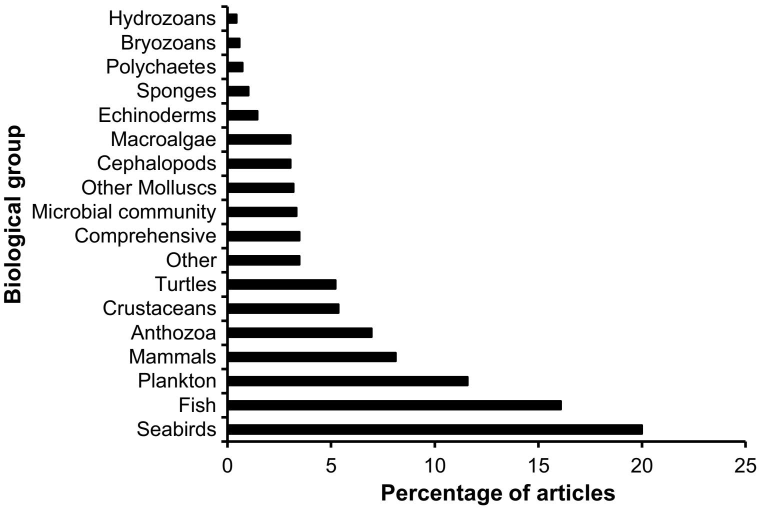


Fig. 4 Percentage of studies in each biological group

year. 69% of all identified studies are from three territories: South Georgia and the South Sandwich Islands (SGSSI, 34%), Falkland Islands (19%), and Bermuda (16%) (Fig. 3b). UKOTs within the Caribbean collectively only accounted for 13% of all identified articles. No articles were identified from Akrotiri and Dhekelia Sovereign Base Areas.

The most common biological groups examined were seabirds (20% of all identified articles), fish (16%), plankton (11%), marine mammals (8%), and anthozoa (7%) (Fig. 4). Only a few studies (4%) comprehensively considered whole ecological communities (Fig. 4). Penguins were the most commonly studied seabird (29% of all seabird articles) followed by albatross (26%) and petrels (20%). Elasmobranchs only featured in 10% of all articles that studied fish or fish communities. Seals (47% of all mammal articles) and whales (30%) were the most commonly studied marine mammals.

Focal biological groups were unevenly distributed around the UKOTs. Seabirds dominated articles in Tristan da Cunha (53% of 45 articles) and the Falkland Islands (38% of 126 articles). Elsewhere, most articles focused on fish in the Cayman Islands (42% of 47 articles) and BIOT (35% of 41 articles), and marine mammals (40% of 5 articles) in Gibraltar. Studies were mostly concerned with biological, ecological and biogeography related questions whereby life history or genetic characteristics, foraging and species distributions and movement patterns featured most highly. Only 10% (N = 67) of articles explicitly considered management or conservation implications as their main focus. 15% (N = 101) of articles addressed at least one threat as part of their research. Fisheries, including directed and non-directed fisheries impacts, were the most commonly considered anthropogenic stressor (4% of all identified articles) followed by climate change and its associated impacts (4%), pollution (3%) and invasive species (2%). Other threats considered by studies included disease, noise, habitat loss, extreme weather events, and crown-of-thorns outbreaks however a lack of comprehensive spatial data for these threats prevented further spatial analysis.

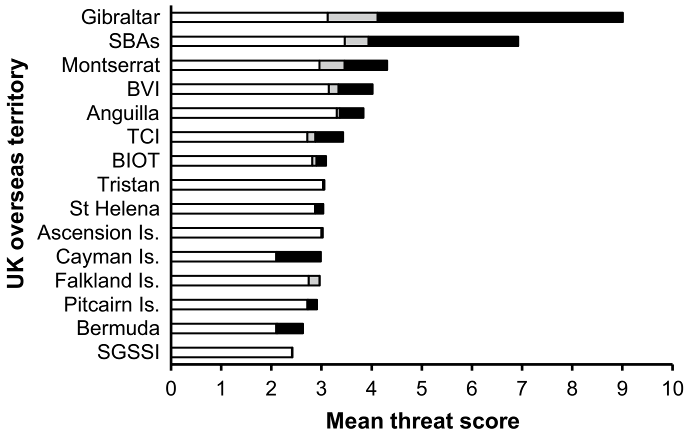


Fig. 5 Mean threat score for each UK Overseas Territory across 'climate change associated' (white), 'fishing' (grey) and 'other human' (black) stressors. Abbreviations: *SBAs* Akrotiri & Dhekelia Sovereign Base Areas, *BVI* British Virgin Islands, *TCI* Turks & Caicos Islands, *BIOT* British Indian Ocean Territory, *Is.* Island(s), and *SGSSI* South Georgia and South Sandwich Islands

Spatial analysis of biodiversity threats

Spatial analyses show 'climate change associated' stressors pose the greatest threat to all the UKOTs with 'fishing' and 'other human' stressors representing lesser threat (Fig. 5). On average, UKOTs within the Mediterranean Sea experience the greatest level of overall mean threat, followed by those within the Caribbean (Fig. 5). However, the intensity of threat varies spatially both within and between UKOTs (Fig. 6). Tristan da Cunha, Anguilla, BVI, Gibraltar and Akrotiri & Dhekelia SBAs experience the greatest level of mean 'climate change associated' threat and high relative threats across their national waters (Fig. 6a). 'Climate change associated' threat declines towards Antarctica with SGSSI experiencing the lowest level of mean threat compared to the other UKOTs. The majority of UKOT waters experience low relative threat from 'fishing' with areas of concentrated use located around coastlines (e.g. Akrotiri & Dhekelia SBAs, Caribbean UKOTs), EEZ boundaries (e.g. Pitcairn Islands, BIOT, Caribbean islands, Ascension Island) and high productivity areas (e.g. Falkland Islands) (Fig. 6b). UKOTs within the Caribbean and Mediterranean together with Bermuda experience the greatest level of relative 'other human' stressors across their marine regions (Fig. 6c), although overall levels remain low for most of the UKOTs (Fig. 5).

Sea level rise was the dominant 'climate change associated' stressor across all territories accounting for, on average, more than 30% of the mean threat score for 'climate change associated' threat across eight of the sixteen territories (Table 3). Mean 'climate change associated' threat scores for the UKOTs were relatively evenly distributed across the three remaining component stressors (Table 2, Table 3). Ocean acidification accounted for between 6 (SGSSI) and 32 (TCI) percent of the mean 'climate change associated' threat facing UKOTs, and explained more than 20% of the mean 'climate change associated' threat score for twelve territories. Sea surface temperature anomalies and UV radiation each accounted for between approximately 13 and 30% of the mean 'climate change associated' threat score for each territory.

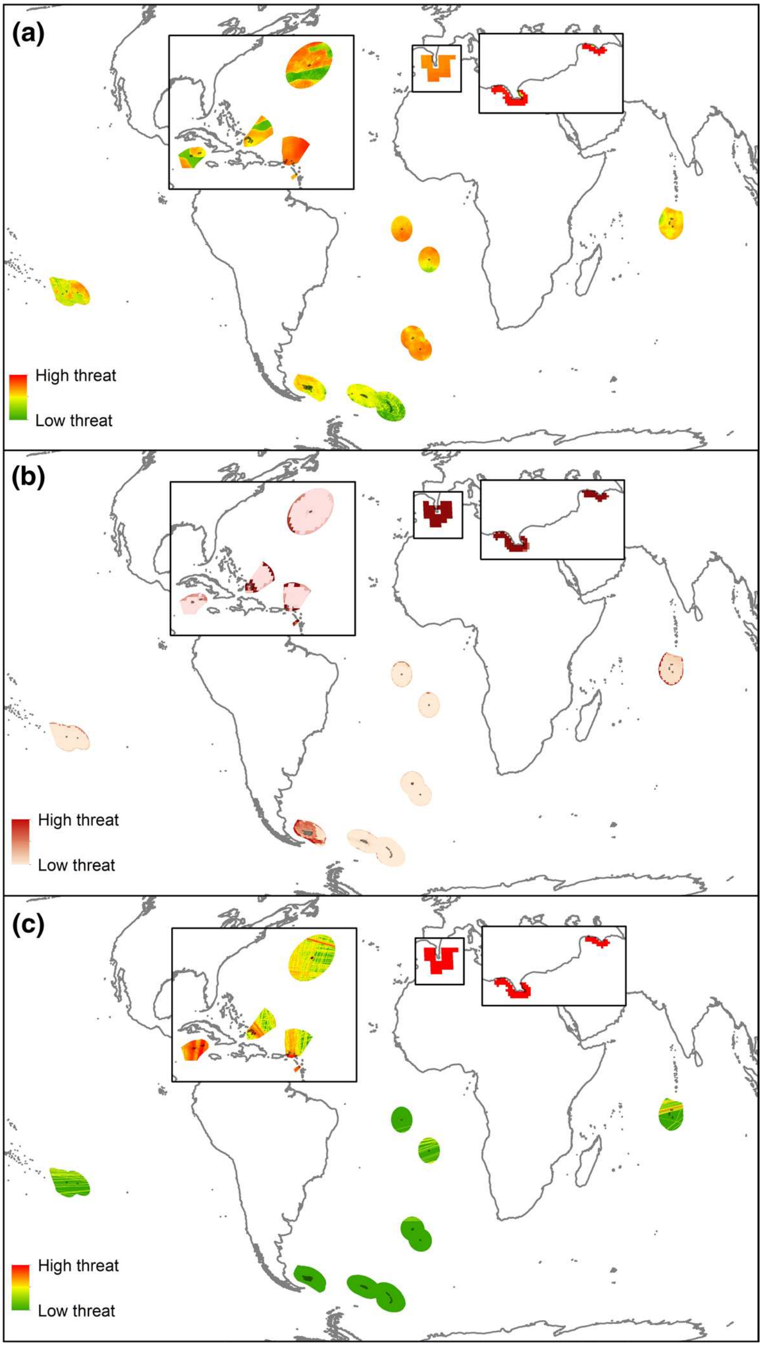
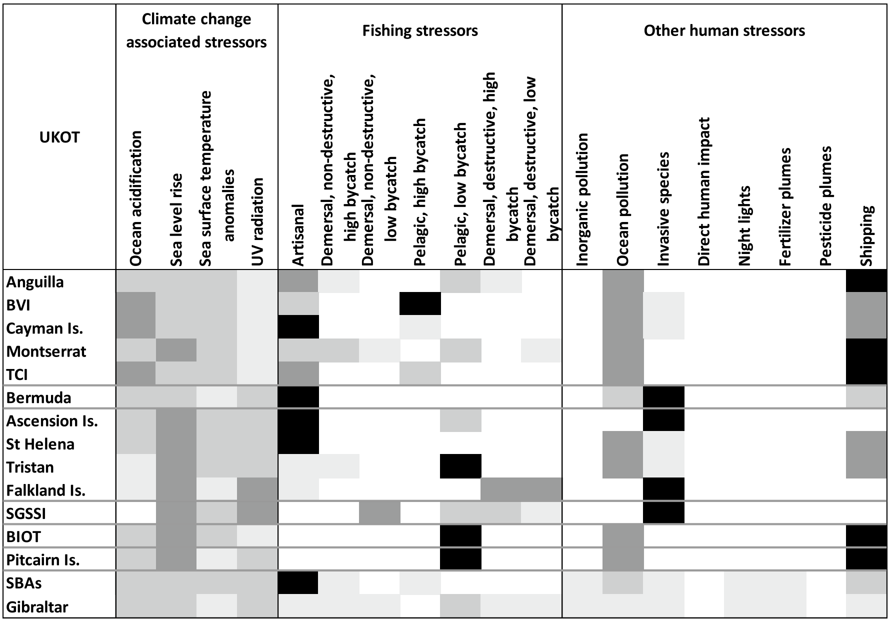


Fig. 6 Additive threat models for **a** 'climate change associated', **b** 'fishing', and **c** 'other human' stressors experienced by UK Overseas Territories

Table 3 Contribution of each component threat to the mean 'climate change associated', 'fishing' and 'other human' threat scores for each UK Overseas Territory. Black cells represent cases where the component threat contributed > 50% of the mean threat score for the territory in question, dark grey 30–50%, mid-grey 20–30%, light grey 10–20%, and white < 10%. Dashed horizontal lines group territories into ocean regions. Abbreviations: *UKOT* UK Overseas Territory, *BVI* British Virgin Islands, *Is.* Island(s), *TCI* Turks and Caicos Islands, *Tristan* Tristan da Cunha, *SGSSI* South Georgia and South Sandwich Islands, *BIOT* British Indian Ocean Territory, and *SBAs* Akrotiri and Dhekelia Sovereign Base Areas. Note that fishing is no longer legally permitted around BIOT and the Pitcairn Islands. 'Pelagic, low bycatch' fishing is shown as contributing > 50% of the mean 'fishing' threat score for each of these UKOTs, however this is concentrated around exclusive economic zone (EEZ) boundaries (Fig. 6) and likely represents overlap between high seas and EEZ boundaries



Most UKOTs are subject to one dominant type of component fishing (Table 3). Montserrat and the Falkland Islands present exceptions to this where most of the fishing categories are relatively evenly represented in Montserrat, and two fishing categories ('demersal destructive fishing high' and 'low bycatch') are equally dominant in the Falkland Islands. Artisanal fishing accounts for the greatest proportion of mean 'fishing' threat score for seven of the UKOTs relative to the other component stressors (Table 3). Note that with the establishment of two no-take Large-Scale MPAs, the Chagos Archipelago MPA and the Pitcairn Islands Marine Reserve (Table 1), fishing is no longer legally permitted in the entirety of the exclusive economic zones around BIOT and the Pitcairn Islands, with the exception of halos around the Pitcairn Islands (i.e. Pitcairn, Henderson, Ducie and Oeno islands) and an offshore reef so the local population can continue fishing for subsistence and trade (Government of Pitcairn Islands 2016). 'Pelagic, low bycatch' fishing is shown as contributing > 50% of the mean 'fishing' threat score for each of these UKOTs (Table 3), however this is concentrated around EEZ boundaries (Fig. 6) and likely represents overlap between high seas and EEZ boundaries.

Ocean pollution and shipping together explain over 70% of the mean 'other human' stressors threat score for nine of the UKOTs and invasive species accounts for more than 80% of the mean 'other human' stressors threat score for four of the remaining territories

(Table 3). However, these component threats are highly interrelated being modelled based on the same raw data (Halpern et al. 2015, 2008). The remaining UKOTs, Gibraltar and the SBAs, have the highest level of 'other human' threat out of all the UKOTs and score consistently highly in all component stressors (Table 3).

Note that many of the UKOTs had no data for one or more areas within their associated waters. Where this occurs, it will lower the mean level of threat for the area concerned and thus make specific locations appear less threatened than others. Further territory-specific analyses would be required to evaluate the extent of these discrepancies as well as to identify particular localised threats and to ground truth modelled data. However, for the purposes of this UKOT-wide analysis, the results presented provide an indication of the main broad threats facing each UKOT relative to the others.

Discussion

The UKOTs are a geographically disparate group of countries politically aligned by the UK government, although each have local governance. Until now, scientific research has been scattered across a disparate literature base presenting challenges for researchers and decision-makers alike to locate and apply all relevant literature to make informed decisions. The research directory we present (Table S1) provides a resource for end-users to quickly and easily identify recent research relevant to their needs, and it is hoped that this will spur continued efforts to maintain this directory and track research knowledge and focus in the UKOTs.

Overall, we found that marine biodiversity within the UKOTs has received consistent, but largely low, levels of scientific interest over the past 12 years (Fig. 3a) and our findings highlight considerable bias in research effort geographically and in terms of biological focus (Fig. 3, Fig. 4). There is a weak inverse relationship between the mean threat score of a UKOT and the number of scientific publications ($r = -0.458$, $p > 0.05$, $n = 16$) suggesting that scientific interest is not being driven by immediate threats. Three territories (SGSSI, Falkland Islands and Bermuda) dominate scientific publications, with thirteen of the remaining territories each having fewer than 50 articles published during the study timeframe, and less than 10 each for six of these (Fig. 3). Focus on these three territories is likely, at least in part, due to existing research infrastructure and associated and established research organisations, e.g. the British Antarctic Survey, the South Atlantic Environmental Research Institute, the Bermuda Institute of Ocean Sciences. Greater resources to establish similar infrastructure and expertise across other UKOTs would facilitate more balanced research. Studies on seabirds, fish and plankton account for almost 50% of the focus of all research, with focal biological groups understandably distributed differently across the territories. Unexpected, however, was the lack of practical management or conservation considerations or focus on anthropogenic threats within research. Instead, research appears to be predominately focused on basic biological questions (e.g. growth, reproduction) and species taxonomy or distribution. The predominance of such studies highlights the lack of knowledge regarding marine life in the UKOTs, particularly with regards informing broader ecosystem-scale management, concurring with Churchyard et al.'s (2016) findings.

Interestingly, apart from the Pitcairn Islands, no evidence of new or renewed interest in marine biodiversity following the announcement or designation of large-scale marine protected areas was found. However, this may be because of the time required for scientific publication and the relative newness of four of these (Table 1). Moreover, many of the

UKOTs are remote and are difficult and expensive to travel to with most lacking essential research platforms such as survey vessels, although if work can be done locally or in partnership with local communities then costs may be reduced and associated in-country benefits will be greater as local expertise develops. Obtaining the necessary funds to mobilise research equipment and personnel therefore adds an additional lag time, particularly with limited funding sources for work on environmental issues in the UKOTs. Furthermore, considerable work is done in the UKOTs by, or for, non-governmental and governmental organisations (e.g. Dallison and Ferguson 2017; Irving and Dawson 2012; MarEcol 2017) and much valuable knowledge is likely contained in reports produced by these organisations. With publication times of grey literature also likely to be more rapid than formal scientific publications, extension of this work to include grey literature would be beneficial. Given the recent and planned designation of many of the large-scale MPAs in the UKOTs, it is also likely that additional research is in its infancy with few results to report as yet. For example, the Bertarelli Foundation has provided funding from 2017 to 2020 to develop a programme in marine science for BIOT, coordinated by the Zoological Society of London (ZSL), but research results are yet to be published.[2]

This study presents an assessment of the extent and intensity of threats being experienced by the marine environment of the UKOTs, and showed that those with higher human populations experience greater levels of 'fishing' and 'other human' stressors, but that all UKOTs are affected by 'climate change associated' threats. For the majority of UKOTs, fishing appears to be of relatively low threat and highly localised (Fig. 6b). With recent designation of large-scale no-take MPAs covering the EEZs of BIOT and the Pitcairn Islands prohibiting fishing, and stronger marine management around other UKOTs implemented and planned to reduce fishing impacts (Table 1), the challenge is now to ensure effective enforcement to prevent illegal, unreported and unregulated fishing in these areas (O'Leary et al. 2018). Nonetheless, site specific research to ground truth these findings and provide additional threat data to better inform spatial management is required. Our study considered threats within UKOT national waters. However, the high connectivity of the marine environment means that human activities and threats in regions adjacent to UKOT waters can also affect the status of their biodiversity. Illustrating this is the higher level of fishing effort observed around many of the UKOT outer marine limits (Fig. 6b) and further studies may wish to consider external threats such as the regional use of Fish Aggregating Devices (Davies et al. 2014) and pollution incidents (Richardson et al. 2017).

Much effort is spent on research to prioritise areas and species in greatest need of conservation action. However, while species are the building blocks of ecosystems, it is typically not cost-effective to approach conservation on a species-by-species basis, particularly where information is poor (Likens and Lindenmayer 2012). Our findings suggest that research within the UKOTs needs to move beyond target species to ecosystems more broadly, and place greater attention on the effects of anthropogenic impacts on these. This is particularly important given the increasing extent of anthropogenic impacts facing marine environments. For example, climate change has affected UKOTs through bleaching events (McWilliams et al. 2005; Perry et al. 2015) and increased frequency and severity of storms (IPCC 2013, 2014; Shuckburgh et al. 2017). Increasing recognition of the extent of impacts from marine plastics (Boehm et al. 2017; Jambeck et al. 2015) also requires attention within the UKOTs where widespread plastic debris has been reported (e.g. Lavers

[2] ZSL (2017) UK Overseas Territories Chagos Archipelago. [online] www.zsl.org/regions/uk-overseas-territories/chagos-archipelago.

and Bond 2017; Readman et al. 2013; Walker et al. 1997). Nonetheless, one threat that has received greater publicity and management attention is the impact of invasive mammalian predators (e.g. cats, rats) on seabirds across the UKOTs which have been the subject of eradication schemes (Dawson et al. 2014; Hilton and Cuthbert 2010; Martin and Richardson 2017).

While the logistics of undertaking marine science in many of the remote UKOTs are demanding, the lack of research being undertaken in many of the UKOTS is a matter of concern for decision-makers tasked with undertaking evidence-based marine environmental management. Furthermore, where relevant studies are available, the representativeness of their findings for wider application may be limited due to a lack of replication, limited sample sizes, and discrete sampling.

Box 1: Research and conservation implementation needs in the UKOTs

Effective conservation and management relies on good quality information, underpinned by research and long-term monitoring. However, our research shows there is an inadequate marine scientific evidence base on which to effectively inform marine conservation and management decisions for the UKOTs. Here, we make 3 key recommendations highlighting research and conservation implementation needs in the UKOTs

(1) Expand the evidence directory to include grey literature and encourage greater collaborative research

The evidence directory we compile here is limited to scientific publications however much activity is ongoing in the UKOTs beyond academic circles. It would therefore be beneficial to expand the evidence directory to include grey literature published across the UKOTs. Identifying grey literature is, however, time-consuming and requires a clearly designed, comprehensive and transparent strategy (Haddaway and Bayliss 2015) and it will be necessary to ensure adequate resources and capacity to undertake this task. To increase the effectiveness of all forms of scientific investigation in the UKOTs, greater collaborative research is required, and efforts need to address local interests and stakeholder needs. Findings should be widely disseminated and available for interactive use by making datasets and knowledge available and more accessible through scientific channels. This would help prevent duplication of field work, enable evidence gaps to be more effectively targeted, and enhance technical capacity within the UKOTs

(2) Design and undertake research to inform future marine environmental management, particularly on the lessor studied UKOTs and on ecosystem structure, function and response to pressures

Eight of the 14 UKOTs had less than 25 scientific articles published on their marine environment between 2007 and 2017 (Fig. 3b). Knowledge of the marine environment for Akrotiri and Dhekelia Sovereign Base Areas is poorest with no articles identified. Other UKOTs were also poorly studied: for example, Gibraltar was only studied by five articles; Montserrat and the Pitcairn Islands were both studied by only seven articles; and St Helena by eight articles. Few studies comprehensively considered whole ecological communities and there was substantial bias present in the evidence base towards particular biological groups (Fig. 4). Greater efforts are required to direct resources at studies designed to improve ecosystem understanding and generate management-relevant information. To improve research relevance, involvement of policymakers, practitioners, key stakeholder groups, and local communities, where present, is recommended in the early stages of research design.

(3) Increase understanding of territory-specific threats to better target management against current and future pressures

Conservation and management of marine resources requires detailed data, which is currently limited for many of the UKOTs. While the analyses presented within this study allow comparisons to be drawn from across the UKOTs, territory specific analyses are required to ground truth modelled data and to identify particularly localised pressures in the region. Greater research efforts are therefore required to focus on pressures in the UKOTs and in regions connected to UKOT waters to better inform management

Conclusions

With the vast majority of the UK's biodiversity contained within its 14 Overseas Territories (FCO 2012), ensuring effective conservation and management will be critical for the UK to meet its international commitments under the Convention on Biological Diversity and Sustainable Development Goal 14. However many UKOTs suffer from a lack of capacity and resources to undertake research or enact conservation and management measures (Churchyard et al. 2016; Forster et al. 2011). Additional and continued investment in research and management is therefore required in the Overseas Territories. Positively, this need is being recognised, with the UK government committing funds to support the implementation and monitoring of large-scale marine protection in the UKOTs, focusing initially on BIOT, SGSSI, BAT, the Pitcairn Islands, Ascension Island, St Helena, and Tristan da Cunha (UK Government 2017). This will help advance scientific and management efforts within these areas.

Loss of biodiversity is recognised as having negative consequences for ecosystem function and service provision (Duffy et al. 2016; Gamfeldt et al. 2015, 2012; Howarth et al. 2014; Oliver et al. 2015; Reich et al. 2012; Soliveres et al. 2016), making biodiversity critical for human health and well-being (Diaz et al. 2006). Effectively managing the marine environment to safeguard against future biodiversity loss will therefore be crucial for continued ecosystem functioning and service provision in the face of changing environmental conditions and an ever-expanding human footprint (Halpern et al. 2015; Roberts et al. 2017; Watson et al. 2013). Areas subject to fewer human activities contain the most intact communities and ecosystems (D'agata et al. 2016; Graham and McClanahan 2013), and so given the remote nature of many of the UKOTs and the relatively low levels of direct anthropogenic threat currently facing marine life in their waters (Fig. 6), there is an opportunity to develop proactive and precautionary marine management. Strategies such as large-scale marine protected areas where appropriate or networks of smaller protected areas contained within more extensive marine spatial plans will be essential to ensure this opportunity is realised (Ban et al. 2017; Boerder et al. 2017; Davies et al. 2017; O'Leary et al. 2018; Spalding et al. 2016). Governments of the UK and its Overseas Territories have made, or are in the process of making, a substantial contribution to global conservation efforts through the designation of large-scale marine protected areas (Table 1), as well as to improved local management (e.g. Augé et al. 2015; Pelembe et al. 2016). Nonetheless, with benefits of protection directly linked to the level of protection given (Edgar et al. 2014) and the extent of that protection (O'Leary et al. 2016b), it is essential that future management ambition matches those of the desired outcomes. Furthermore, while precautionary management is warranted for many of the UKOTs, others with larger human populations may already have degraded marine ecosystems and so conservation efforts are required to focus of preventing further loss and encouraging recovery. Both approaches should be prioritised to maximise the chances of generating improvements to marine ecosystems and local populations, while preventing declines in marine biodiversity elsewhere. This will need to be designed with, and complemented by, other sectoral management measures to deliver the greatest benefits to marine ecosystems and local people (O'Leary et al. 2018).

While we conclude that there is an inadequate scientific marine evidence base to effectively inform marine conservation and management decisions for the UKOTs, policy is also informed by evidence from sources such as expert knowledge, stakeholder reports, and experiential evidence (O'Leary et al. 2016a and references therein), as well as inferred knowledge from other places and the precautionary principle. Nonetheless, there is an urgent need to design and undertake research to inform future marine environmental management, and to increase efforts on the lesser studied UKOTs (Box 1). To meet global goals for effective marine management (Convention on Biological Diversity 2010; United Nations 2015), the UK government must ensure greater focus on biodiversity research and management measures across all UKOTs waters.

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